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14. ABSTRACT
Sheet piles, used as retaining walls, wharfs, and piers, are typically made of unprotected carbon steel (CS). This type is affordable and the general corrosion rate (wastage) is predictable. Despite the long and successful use of CS sheet pilings, there are reports of localised corrosion of CS pilings that have been identified as microbiologically influenced corrosion (MIC) ie, corrosion that is a result of the presence and activities of microorganisms. Microorganisms can produce localised attack including pitting, enhanced erosion corrosion, enhanced galvanic corrosion, stress corrosion cracking, and hydrogen embrittlement of CS Microorganisms do not produce a unique corrosion morphology in CS that could not be produced abiotically.

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Microbiologically influenced corrosion of pilings

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Sheet piles, used as retaining walls, wharfs, and piers, are typically made of unprotected carbon steel (CS). This type is affordable and the general corrosion rate (wastage) is predictable. Despite the long and successful use of CS sheet pilings, there are reports of localised corrosion of CS pilings that have been identified as microbiologically influenced corrosion (MIC) ie. corrosion that is a result of the presence and activities of microorganisms. Microorganisms can produce localised attack including pitting, enhanced erosion corrosion, enhanced galvanic corrosion, stress corrosion cracking, and hydrogen embrittlement of CS. Microorganisms do not produce a unique corrosion morphology in CS that could not be produced abiotically.[i]

Corrosion of pilings in marine and estuarine environments

Accelerated low water corrosion (ALWC) is a particularly aggressive form of localised corrosion that has become a high profile problem, associated with unusually high corrosion rates of unprotected or inadequately protected CS pilings in marine and estuarine waters. The UK Institution of Civil Engineers described ALWC as "a matter of national importance".[ii]

ALWC is a global phenomenon having been reported in all climatic conditions on unprotected steel pilings in contact with saline water (ie. seawater and brackish water) that is subject to tidal influences.[iii] A survey of port and harbour authorities in five Western European countries concluded that at least 13 percent of the ports were affected by ALWC.[iv]

The term ALWC does not define a corrosion mechanism. Instead the term denotes the precise location of the corrosion on the exposed pilings (see Figure 1). Average corrosion rates in the range of 0.3 to 1.2 millimetres per side per year have been reported. ALWC has a distinct appearance, patches of lightly adherent, bright orange and black (iron sulphide rich) deposits over a clean, shiny and pitted steel surface.[v]

As pits deepen and become more numerous, they overlap, producing terraced holes. Corrosion products contain magnetite, iron sulphides, and green rust (an unstable iron oxy-hydroxide sulphate complex).

Mechanisms and mitigation

A report by Gehrke and Sand concluded that ALWC was due to the combination of sulphate-reducing bacteria (SRB) and sulphur oxidising bacteria (SOB) in the fouling layers on the pilings.[vi] The organisms co-populate the same spatial regions on the pilings. At low tide the biofouling layer is oxygenated whereas at high tide anaerobic areas develop. Sulphides produced by SRB are converted to sulfuric acid by SOB, creating an extremely corrosive environment. (see Figure 2a).

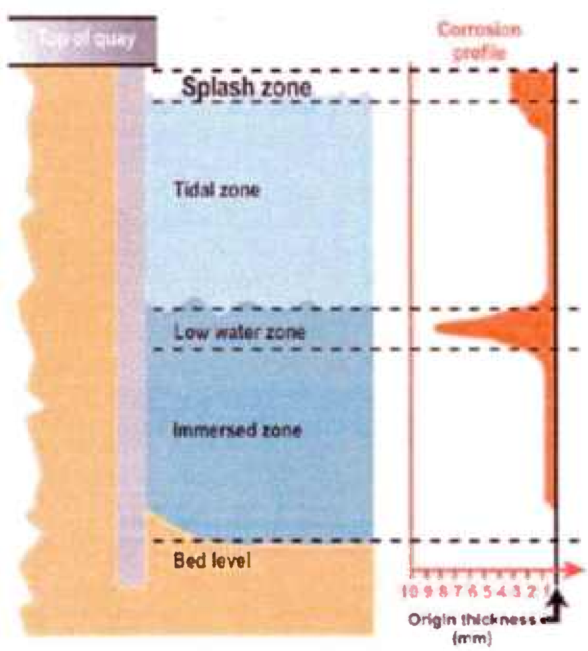

Figure 1: Schematic of ALWC illustrating relationship of water level and degree of corrosion. Taken from Kopczynski (PII 2010).

Melchers and Jeffrey found: "The increased occurrence of ALWC reported in recent years is most likely the result of elevated levels of water pollution in the waters to which the steel piling has been exposed over its lifetime, irrespective of whether water pollution is currently decreasing."[vii]

A later review of data from a 27-year period related to ALWC concluded that the severity of ALWC correlated with the concentration of dissolved inorganic nitrogen (DIN), "a critical nutrient for microbiological (bacterial) activity in seawater." It is suggested that this observation could be used to predict the long-term risk of ALWC.[viii] It has also been reported that protective coatings, sacrificial anodes or impressed current cathodic protection were effective in mitigating ALWC.[ix]

Corrosion of pilings in freshwater environments

Accelerated corrosion has been reported for CS pilings in the Duluth-Superior Harbour (DSH), Minnesota, a fresh water estuary.[x] DSH pilings that are over 30 years old are either completely or partially perforated by localised corrosion (see Figure 2b). The corrosion extends from the air/water interface to a depth of about 3 metres, but with decreased attack from 1.2 to 3 metres. The position of the air/water interface is not significantly influenced by tides. Below 3 metres where zebra mussel attachment begins there is little corrosion. Corroded DSH pilings have an orange rusty appearance characterised by tubercles, dense mounds of corrosion products (see Figure 3). The average pit depth, a measure of localised corrosion, in a three-year study ranged between 670 micrometres to 788 micrometres, 7-8 percent of the total thickness of the coupons. Pit depth varied with location and increase in pit depth was not linear over the three-year exposure.

Mechanisms and mitigation

A 2009 study has demonstrated that corrosion of carbon steel pilings in DSH was due to deposition of copper under tubercles of iron-oxidising bacteria (IOB). IOB oxidise iron and produce dense deposits of intact and/or partly degraded remains of bacterial cells mixed with amorphous hydrous ferric oxides. A galvanic couple was established between the copper layer and the iron substratum. In laboratory experiments, the galvanic current depended on the concentration of dissolved copper in the lake water.[xi] A recent study used genetic techniques to quantify the abundance of IOB at multiple sites in the DSH over multiple years. They demonstrated that tubercles in the DSH were enriched with IOB compared to the biofilm on adjacent surfaces. However, long-term corrosion was not related to IOB abundance or dissolved copper concentration.[xii] Both studies concluded that a combination of microbiological and chemical factors influenced the rate of corrosion. An additional report evaluated coatings for DSH pilings over a four-year period. Some of the coatings provided an effective barrier that prevented tubercle formation and MIC.

Figure 2a: (Left) Piling deterioration due to ALWC. Figure 2b: (Right) Corrosion of piling in Duluth Superior Harbour.

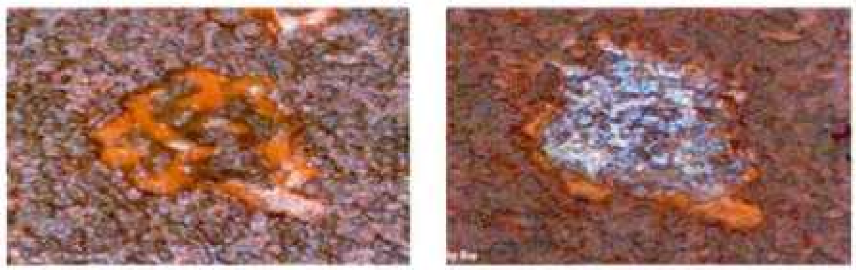

Figure 3: Tubercle on carbon steel exposed in Duluth Superior Harbour before (left) and after (right) removal of tubercle.

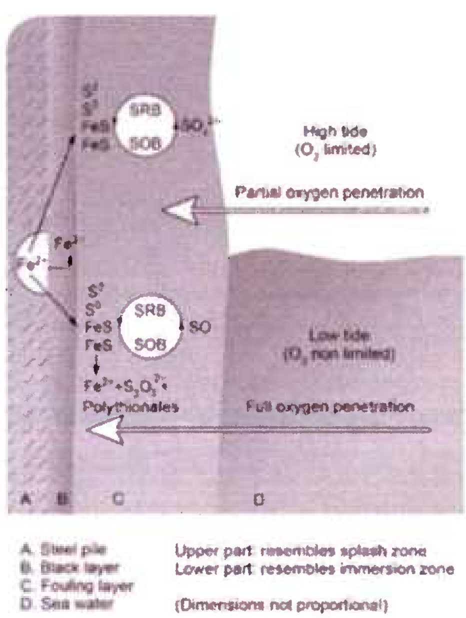

Figure 4: Schematic representation of the chemistry and reactions associated with ALWC. Reproduced with permission from NACE International, Houston TX. All rights reserved. Copyright NACE International 2003.

Diagnosing MIC in harbours

The involvement of microorganisms in the corrosion of CS pilings cannot be surmised by evaluating the morphology of the localised corrosion. Furthermore quantification of bacterial types does not provide a predictive capability. The following are required for an accurate diagnosis of MIC: a sample of the corrosion product or affected surface that has not been altered by collection or storage, identification of a corrosion mechanism, identification of microorganisms capable of growth and maintenance of the corrosion mechanism in the particular environment, and demonstration of an association of the microorganisms with the observed corrosion.

In summary

Corrosion rates for ALWC and corrosion in DSH are similar ie. 0.3 millimetres per-year and higher. However, there are obvious differences in the observations in DSH and reports of ALWC (see Figure 4). ALWC is in the low water zone, just below the tidal zone, in saline waters containing gram per litre quantities of sulphate. DSH is a fresh water harbour with milligram per litre concentrations of sulphate. Corrosion in DSH is localised to the top 3 metres below the surface of the water and water depth is not significantly influenced by tides. Despite these differences both ALWC corrosion and corrosion in DSH have been attributed to MIC. In both cases, a combination of biological, chemical and physical events contribute to the corrosion. The specificity of metal/microbe/electrolyte interactions makes it difficult to predict the likelihood and rate of MIC in harbours. MIC on CS pilings can be prevented.

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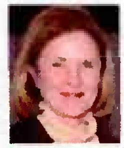
About the author



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